Improving Building Energy Efficiency in the U.S:
Technologies and Policies for 2010 to 2050

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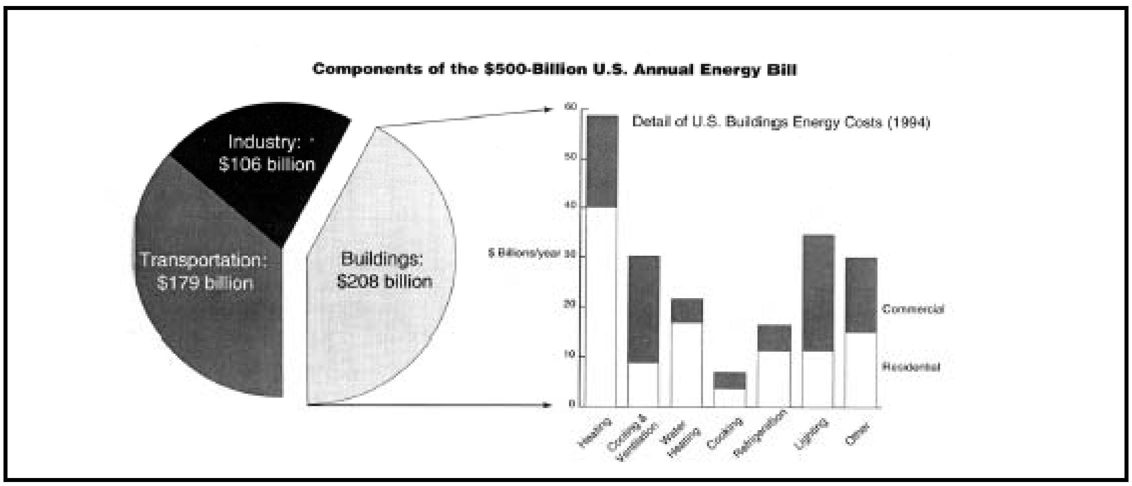
1.0 The Significance of Building Energy Use

The building sector is the biggest ‘player’ in the energy use equation and can have the greatest impact on maximizing energy supply and minimizing energy demand while providing measurable gains for productivity, health and the environment (figure 1, 1997 Interlaboratory working group). The U.S. Green Building Council has summarized the energy and environmental importance of this sector of the economy: Commercial and residential buildings use 65.2% of total U.S. electricity and over 36% of total U.S. primary energy. Buildings use 40% of the raw materials globally and 12% of the potable water in the United States. Building activity in the U.S. also contributes over 136 million tons of construction and demolition waste (2.8 lbs/person/day), and 30% of U.S. greenhouse gas emissions (USGBC 2001).

Figure 1 (Interlaboratory Working Group 1997)



Illustrating the scale of the impact that building energy efficiency can have on national goals - if improved standards for residential refrigerator efficiencies had not been introduced in 1975, over 40 GW of additional power plant generation would have been needed in 2001, producing 32 million tons of carbon (MTC). Of equal importance, EER standards for commercial rooftop air conditioners have avoided 135 GW of peak electricity load with associated carbon savings of over 100 MTC (Rosenfeld et al 2004).

The building sector currently receives the least federal attention for research and development, despite its large potential for addressing climate change through: reducing primary energy requirements and emissions, replacing fuel sources with non-carbon based alternatives, and supporting effective sequestration of carbon in the built environment.

2.0 Five specific directions in building energy efficiency

An evaluation and international comparison of the energy load breakdowns in residential and commercial buildings reveal substantial opportunities for energy efficiency in the building sector. While it is not possible to give a comprehensive list of these opportunities, the following paragraphs illustrate the potential impacts of four specific directions for building energy efficiency in both the 2010 and 2050 time horizons.

2.1 Appliance and equipment energy standards and innovations

The introduction of California and then national standards for equipment and appliance efficiency has had a major impact on national energy use, reducing energy consumption for heating, cooling and refrigeration demands by 25%, 60% and 75% respectively (figure 2a, Rosenfeld et al 2004). The direct relationship of appliance electricity demand and CO_2 production illustrates the value of these energy savings in addressing climate change. The impact of both R&D and standards has enabled refrigerator size and amenities to increase while overall energy use is reduced (figure 2b, Rosenfeld 2004). Four pending appliance standards (clothes washers, fluorescent light ballasts, water heaters and central air conditioners) are projected to save consumers $10 billion in energy costs, improve functionality, and reduce cumulative emissions by as much as 22 MTC through 2010 (US Climate Action Report 2002). The natural replacement cycle of just four building technologies – ballasts, lamps, windows and refrigerator/freezers – with high performance alternatives would save 190 billion kWh of power demand (and 52MTC) by 2010, with an additional 130 billion kWh (and 35MTC) and 0.3Mbod saved by 2050.. There are few engineering obstacles and significant export growth potential in expanding appliance and equipment energy efficiency standards to cover the full range of existing and new equipment being introduced in residential and commercial buildings.

2.2 Shading, Cool Roofs and Cool Development

6% of all US energy is used in cooling residential and commercial buildings (figure 3, Koomey 1996), at an annual cost of $40 billion, and peak power demands of 250 GW. A 5^{o}F rise in neighborhood temperatures – from excessive absorption of solar energy in our increasingly impervious built environment (due to increases in roads, parking lots and roofs) – considerably increases cooling loads. On a national level, the creation of “cool communities” with white roofs, pervious paving, and shade trees would yield a 10% reduction in annual cooling loads, and a 5% reduction in peak cooling loads (Rosenfeld et al 2003). Moreover, CO_2 would be sequestered more effectively by urban trees than an equivalent number of new ‘forest’ trees, and urban flooding would be greatly reduced. In addition to the visible enhancement of our physical environment, cool community planning would yield a 6-8% reduction in smog with commensurate gains in the health of our citizens. Given the cycle time of roof replacements and tree growth rates, immediate federal and state policies and incentives are needed to realize the benefits of “cool communities” by 2020.

2.3 Daylighting and Natural Ventilation

Over 10% of all U.S. energy is used for lighting buildings, much of this during the daytime when daylight is abundant. In combination with the 6% of all U.S energy used for cooling buildings in summer and winter, there is significant argument for the environmental benefits of windows for daylighting and natural ventilation. Given the dominant number of existing buildings – schools, hospitals, offices, manufacturing facilities – originally designed for effective daylighting and natural ventilation, the erosion of natural conditioning is a serious energy cost to the nation. Effective daylighting can yield 30-60% reductions in annual lighting energy consumption, with average energy savings for introducing daylight dimming technologies in existing building at over 30% (Loftness 2002). Emerging mixed-mode HVAC systems, that interactively support natural ventilation or air conditioning, are demonstrating 40-75% reductions in annual HVAC energy consumption for cooling. The effective use of natural conditioning with well designed windows, window controls, and mechanical and lighting system interfaces, promises to yield major energy efficiency gains of up to 5% of all US energy use, reduce risk in power outages, and provide measurable productivity, health and quality of life gains (figures 4 and 5).

2.4 On-site generation, the 'Building as Power Plant'

There are two major arguments for distributed energy systems, particularly the development of on-site energy generation that uses neighborhoods and campuses to ensure system efficiencies. First, U.S. transmission and distribution losses alone totaled 201TWh in 2002, or 55MTC per year. Second, the reject energy from power generation is a prime resource for building energy loads through co-generation of steam, chilled water via absorption chillers, desiccant conditioning, and hot water demands. This co-generation of power and building conditioning dramatically improves power generation efficiencies, from averages of 30% to well over 70% (WADE 2002). Add to this distributed renewable energy sources such as photovoltaic, solar thermal, fuel cells, micro-turbines or biomass, and buildings can actually become power plants – generating more power than they consume (Hartkopf 2002). The U.S. has a limited program in distributed energy systems, with too small a federal investment in combined heat and power technology to support research of CHP linked to renewable sources or CHP fully integrated with buildings and campuses. By 2050, each new building completed should be a net energy exporter – a building as power plant – with a diversity of renewable fuel sources as input (hydrogen, geothermal, solar thermal, solar electric, wind) and a building conditioning cascade that eliminates generation losses (figure 6).

2.5 Land-use and urban growth boundaries

Sprawl and the commensurate abandonment of existing buildings and infrastructures is a serious environmental cost to the nation. A significant portion of the 20 percent growth in transportation energy use in the past ten years is due to increased mileage in single occupancy vehicles - the automobile travel that stitches together the increasingly distributed activities in our daily lives. While fuel efficiency in automobiles will make an impact on this energy and environmental expense, land use innovation will have a far greater impact on both of these factors, as well as health and quality of life. The impact of urban growth boundaries in both Portland and Seattle has been remarkable, with significant investment in infill construction to maximize the utilization of existing infrastructures. Moreover, these cities have emerged as a mecca for young professionals searching for the dynamic, interactive life styles that are only offered in pedestrian, mixed-use neighborhoods. Dr. Richard Jackson of the Center for Disease Control in Atlanta has begun to link a number of chronic ailments in children – depression, obesity and others – to the isolated nature of single use zoning, neighborhoods where kids must be driven to every venue. For 2050, visionaries such as Malcolm Wells and Peter Calthorpe (references) would argue for completely new environmentally balanced approaches to land use and development: Landscapes that are natural stormwater and waste processors, urban growth boundaries to maximize use of existing infrastructures and support pedestrianization, concrete budgets and tree canopy standards - a vision for the future with dramatically reduced cooling, transportation, and water demands as well as improvements in environment, health and quality of life.

3.0 Actions for building energy efficiency and interrelated benefits

In addition to the obvious benefits of reduced energy demand, dramatically accelerated national investments and policies focused on building energy efficiency will contribute to:

- Reduced unnecessary annual energy consumption (figure 2)
- Reduced emissions and climate change impacts (figure 3)
- Increased peak power capacitance and reliability (figures 6 and 7)
- Improved health, human safety and security
- Improved productivity (figures 4 and 5)
- Improved quality of life
- Increased exports - products and services
- Setting a proven example for emerging nations with growing demands

With regards to mitigating against climate change, Greg Kats argues in a study of the costs and financial benefits of green buildings "The vast majority of the world's climate change scientists have concluded that anthropogenic emissions – principally from burning fossil fuels – are the root cause of global warming. The US is responsible for about 22% of global greenhouse gas emissions. Of this 22%, the US building sector is responsible for about 35% of US CO_2 emissions, the dominant global warming gas" (Kats 2003). In addition to energy efficiency gains, building and infrastructure revitalization can have a major impact on reducing urban sprawl and the consequent rapid increases in transportation energy use and emissions from single occupancy vehicles. The critical actions needed to advance building energy efficiency to meet both readily achievable goals in the short term as well as visionary goals in 2050 and beyond include changes in policy, investment and research at the federal, state and industrial level.

3.1 Policy – the market will not take care of it

Energy is cheap, especially if the externalities of pollution, risk, and health are considered. Consumers do not see energy as a large enough component of their disposable income to evaluate the ROI of energy efficiency in the built environment. Deregulation has already reduced the efforts of major utilities to pursue demand side management and weatherization, programs that will have to be picked up by the already budget constrained States. At the same time, power unreliability concerns may lead residential and commercial building owners to purchase inefficient and polluting standby power rather than consider the significant opportunity to invest in energy efficiency. The contributions of buildings to the discharge of four primary pollutants – NO_X, SO_X, CO_2, and particulates – should be fully recognized in the cost of building energy, to catalyze owners and occupants to pursue more environmentally responsible buildings and building use patterns.

Federal and state energy efficiency standards as well as tax incentives are critical. A remarkable example of environmental gain through policy, especially in today's under-regulated, under-incentivized market, has been the introduction of Leadership in Environmental and Energy Design (LEED) by the U.S. Green Building Council. The LEED rating utilizes certification to establish a building's environmental sustainability level related to: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality and innovation in design practices. LEED goals have been adopted by a growing number of major building decision makers in the public and private sector impacting an estimated 3% of new construction with over 50% energy efficiency savings – gains that should be widely adopted.

3.2 Balancing Investment in Supply and Demand

Given the major energy excesses in the built environment, reducing demand must be seen as a major energy source. Investments in "mining" this new energy supply will: yield greater economic benefit for a broader array of industries; provide significant gains in reducing environmental pollution; and ensure a longevity to this "supply" that few other sources can ensure. Unfortunately, the continued federal dollars going into R&D for energy supply outweigh R&D dollars for energy demand 6 to1 (DOE/CR-0059 1999), even though the ROI of energy efficiency dramatically exceeds the ROI of creating new sources. For example, the modest national investments (of around $3M per program) by DOE in R&D for energy efficient ballasts, low-E windows, and refrigerator standards, reaped national benefits of $9,000, $7,000 and $23,000 per dollar invested (Rosenfeld 2004).

3.3 Building Research – An unrecognized federal mandate

Investing in building energy efficiency as a new energy "supply" would dramatically surpass production from new oil supplies and power plant investments, as well as offer sustained "sources" of energy that do not generate greenhouse gases. Yet the combined budgets for building research across the federal government is less than 2% of federally funded R&D, in no way commensurate with the importance of the built environment to our economy and quality of life (Loftness/NSF 2000). Given this paucity of research support, there are only a handful of university Ph.D. programs focused on energy efficiency and environmental quality in the built environment, compared to many dozens of universities with federally funded research related to nano-technology and information security for example. Given that the building sector is 20% of the U.S. economy, over 35% of U.S. energy use and associated environmental quality, and significantly linked to the health and competitiveness of our nation, the federal sector must move beyond today's marginal funding of research in the built environment.

4.0 Conclusions

Energy efficiency in buildings represents a major untapped resource for our energy demands and resultant mitigation of climate change. Standards and removal of market barriers can lead to significant reductions in energy use from key buildings technologies through their natural replacement cycle. A 1997 study undertaken by all five national laboratories determined that building energy efficiency could achieve 230MTC of the 400MTC savings needed by 2010 to meet U.S. targets under the Kyoto Protocol. With the addition of innovative combined cooling, heat and power technologies, a further 170MTC could be achieved, fully meeting 2010 goals through the building sector alone. Over the longer term, expanded building R&D budgets, industry and university based research, and continuing national policies that focus on building energy efficiency, could trigger dramatic improvements in energy and environmental quality in the built environment. Moreover, these investments would ensure ancillary benefits including revitalization of existing buildings and infrastructures, measurable gains in health and productivity, and a positive influence on energy efficient growth in the built environment of developing nations.

In December 2002, the EU adopted the Directive on Energy Efficiency of Buildings with the goal of cost-effective energy savings of 22% by 2010 through four basic actions (Bowie & Jahn 2003):

1. General framework for calculation of the integrated performance of buildings.
2. Setting of minimum standards in new and existing buildings.
3. Energy certification of buildings
4. Inspection and assessment of heating and cooling installations.

The U.S. needs to enact parallel efforts to ensure that the long term implications of decision making in the built environment contribute to our energy, carbon and pollution mitigation, and quality of life goals. With the right policies, incentives and research, building energy efficiency can have a 20%-50% impact on building energy use by 2010, and a 75% impact by 2050, outpacing both the industrial and transportation sectors in national energy savings.

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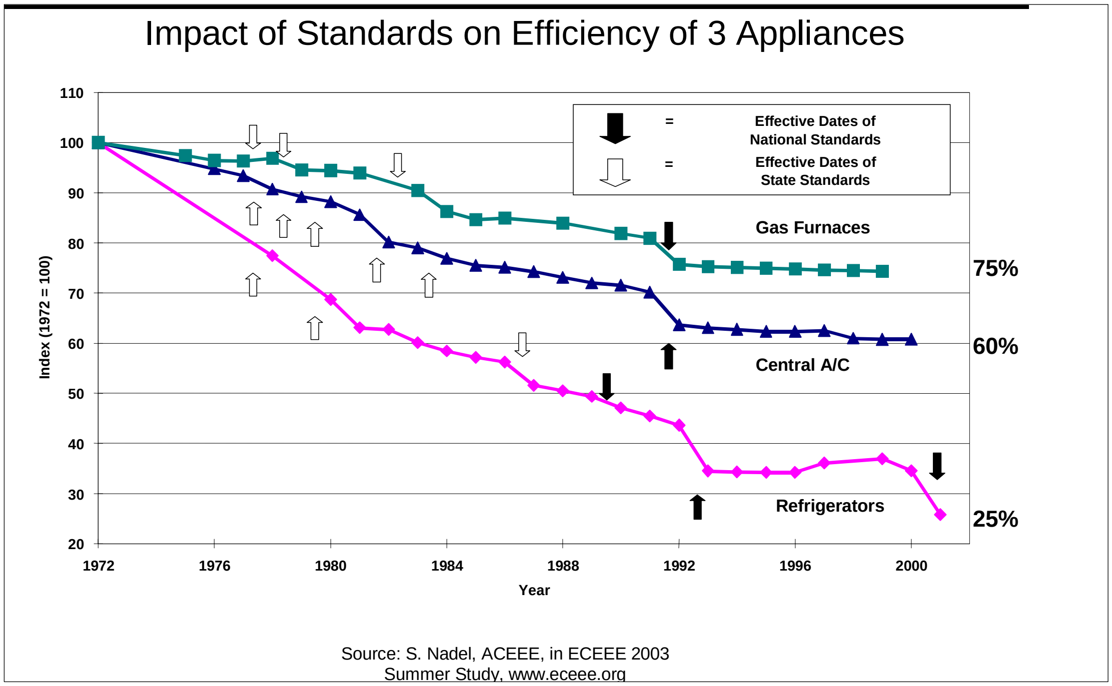
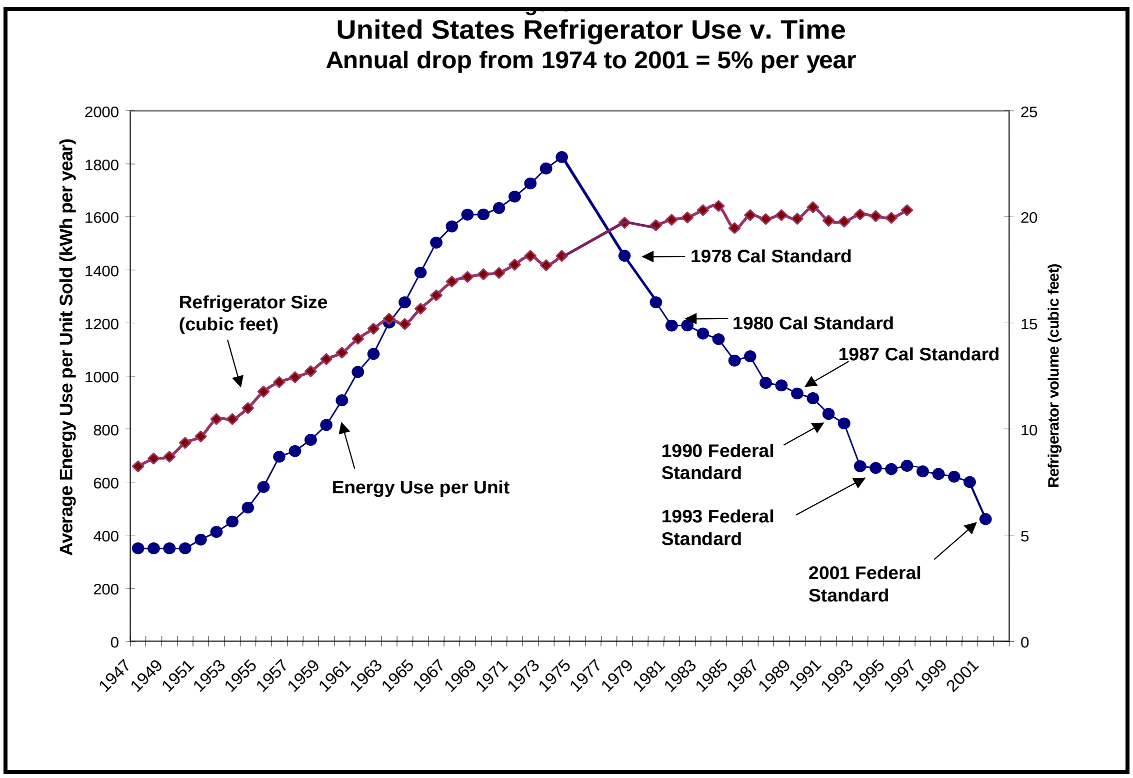
Figures 2a, 2b (Rosenfeld et al 2004)

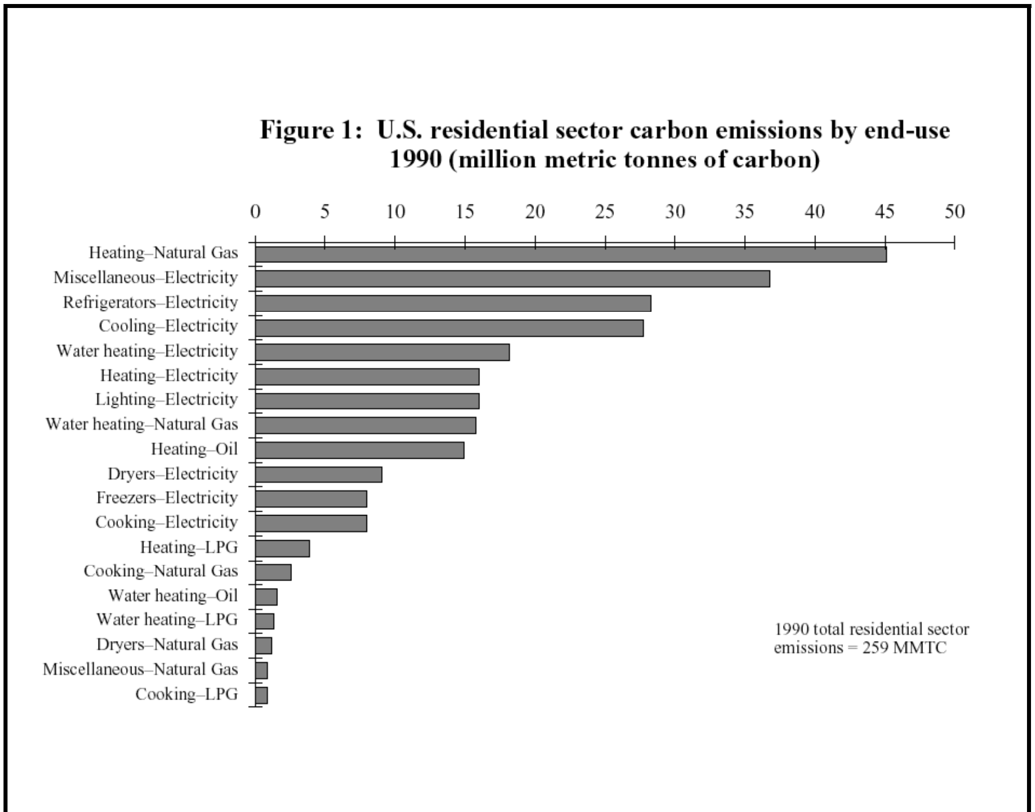


Impact of Standards on Efficiency of 3 Appliances
Index (1972 = 100)
Year
= Effective Dates of National Standards
= Effective Dates of State Standards
Gas Furnaces
Central A/C
Refrigerators
75%
60%
25%
Source: S. Nadel, ACEEE, in ECEEE 2003 Summer Study, www.eceee.org



United States Refrigerator Use v. Time
Annual drop from 1974 to 2001 = 5% per year
Average Energy Use per Unit Sold (kWh per year)
Refrigerator volume (cubic feet)
Refrigerator Size (cubic feet)
Energy Use per Unit
1978 Cal Standard
1980 Cal Standard
1987 Cal Standard
1990 Federal Standard
1993 Federal Standard
2001 Federal Standard

Figure 3 (Koomey 1996)



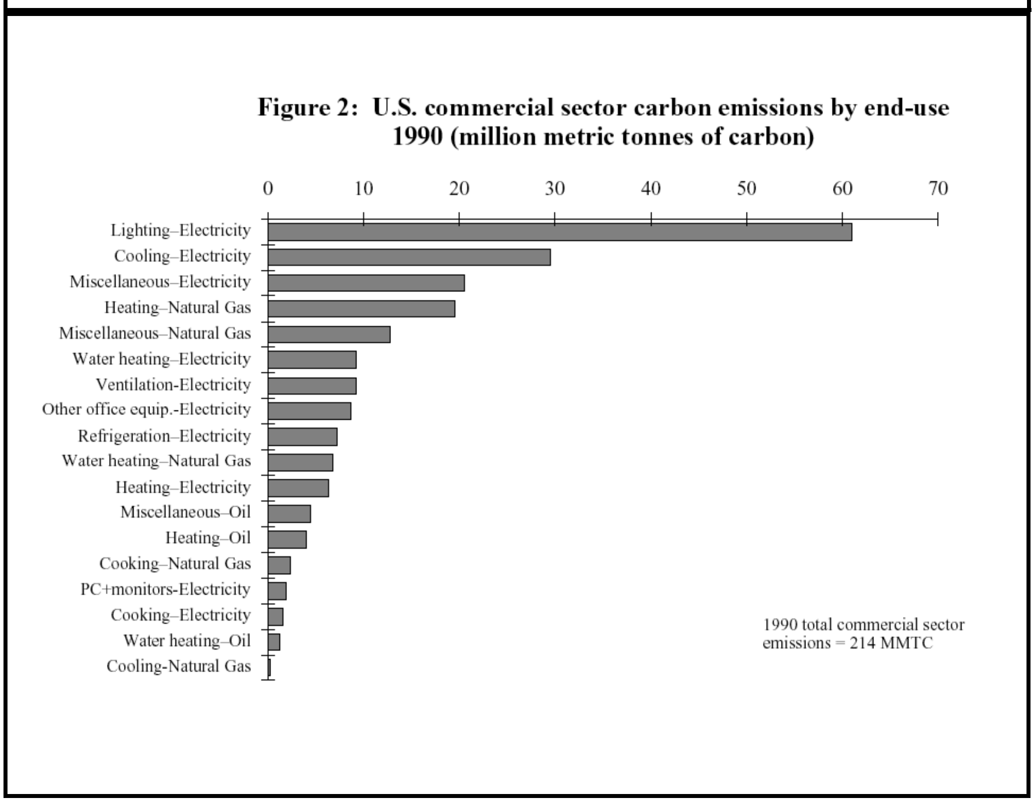
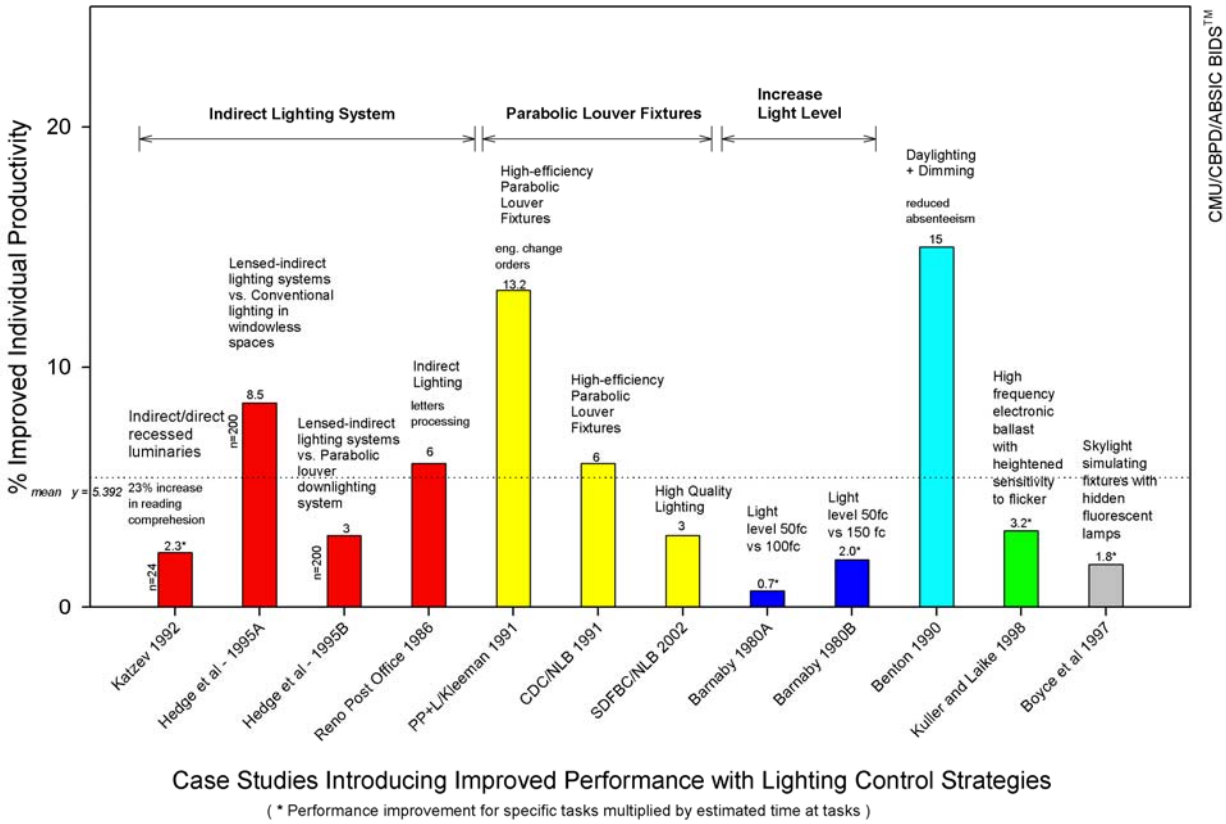


Figure 4

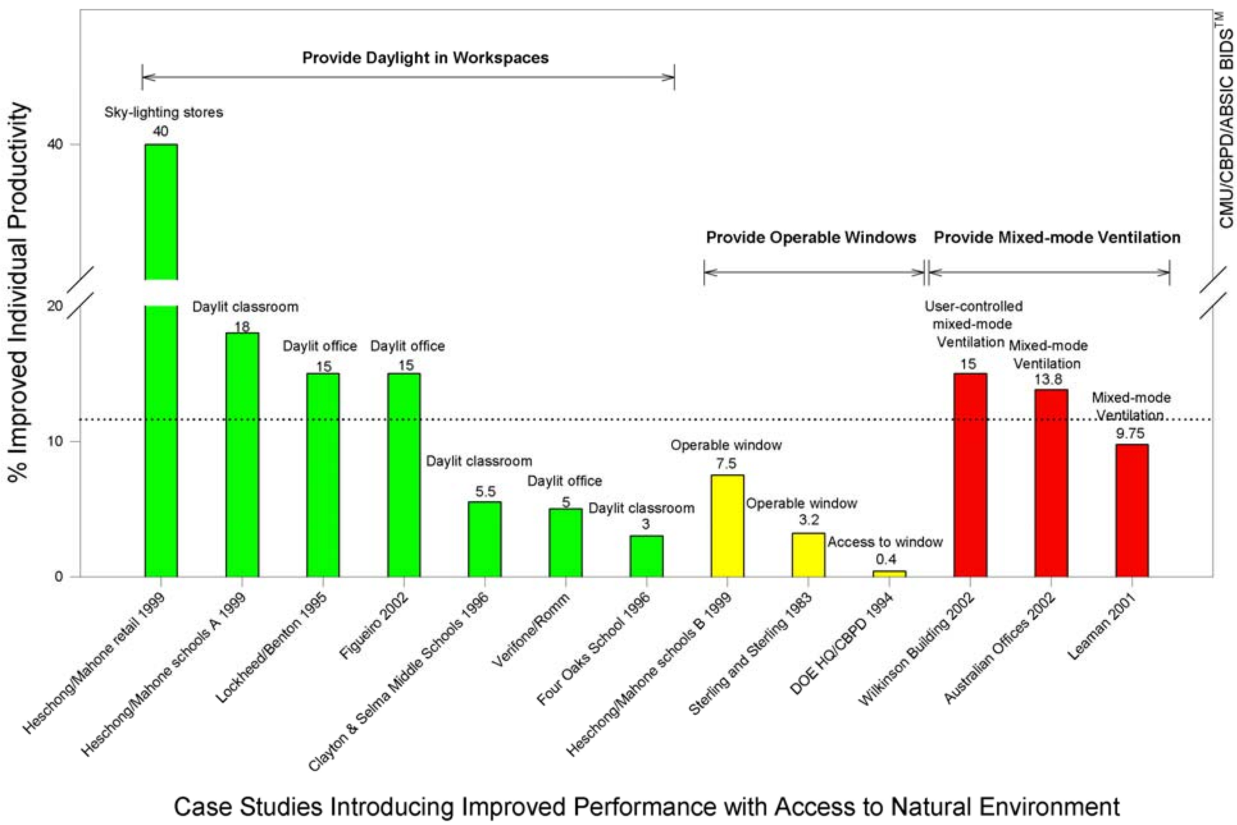


Lighting System Quality Increases Individual Productivity

A range of lighting design strategies have been shown to increase individual productivity: glare-free, high-performance fixture design, including lamp, ballast and lens design; indirect-direct lighting; and improved lighting control systems.

The CBPD team has identified 12 studies linking improved lighting design decisions with 0.7-23% gains in individual productivity. Four of these studies demonstrate 3-23% improved performance at a range of tasks given the introduction of indirect-direct lighting systems. Four studies identify 3-13.2% increases in individual performance resulting from higher quality fixtures – high performance electronic ballasts and parabolic louvers. Four studies identify the contributions of higher lighting levels and daylight simulating fixtures to 0.7-2% improvement in individual productivity at a range of tasks.

figure 5



Access to the Natural Environment Increases Individual Productivity and Health

The importance of access to the natural environment to individual health and productivity is related to a number of design decisions: access to windows and view; daylighting through windows and skylights; natural ventilation and mixed-mode ventilation; and directly accessible landscaped indoor and outdoor spaces.

The CBPD team has identified thirteen studies linking improved access to the natural environment with gains in individual and organizational productivity. Seven of these studies have identified 3-18% increases in individual productivity (including student test results) and 40% increases in sales (an organizational productivity measure) as a result of the introduction of daylight in the workplace. Six studies further indicate that the addition of operable windows for thermal comfort, natural ventilation, or simply access to the outdoors, can impact productivity by 0.4-15%. The upper range of these productivity improvements, from 10-15% increased productivity, are achieved in mixed-mode buildings where operable windows are coordinated with mechanical air conditioning strategies.

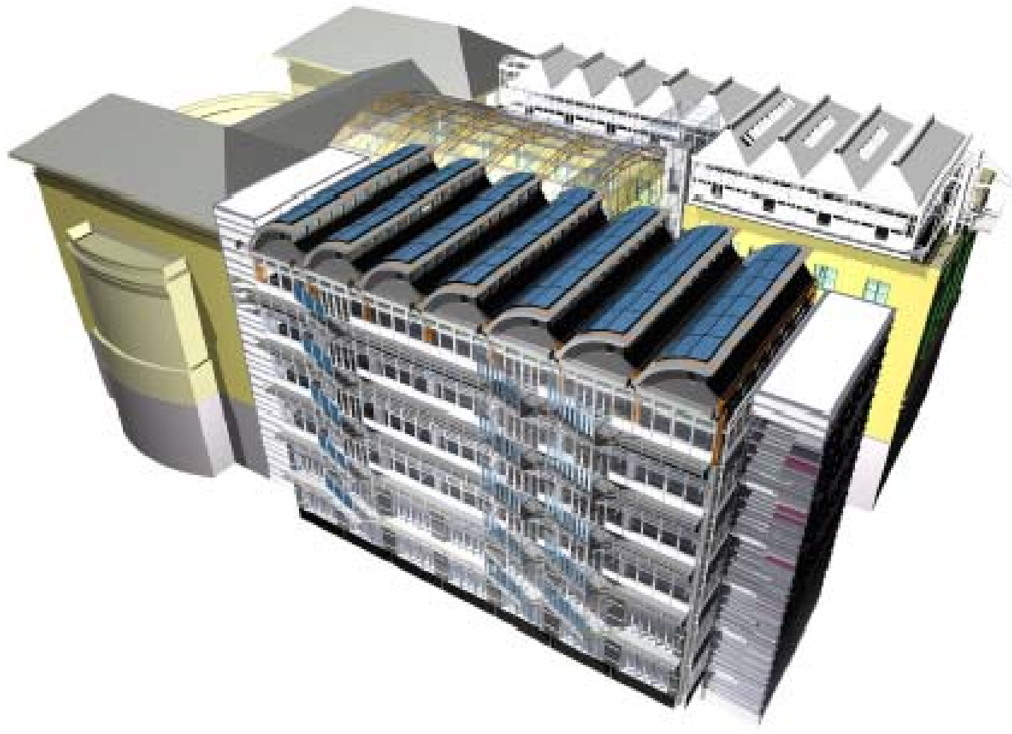


figure 6

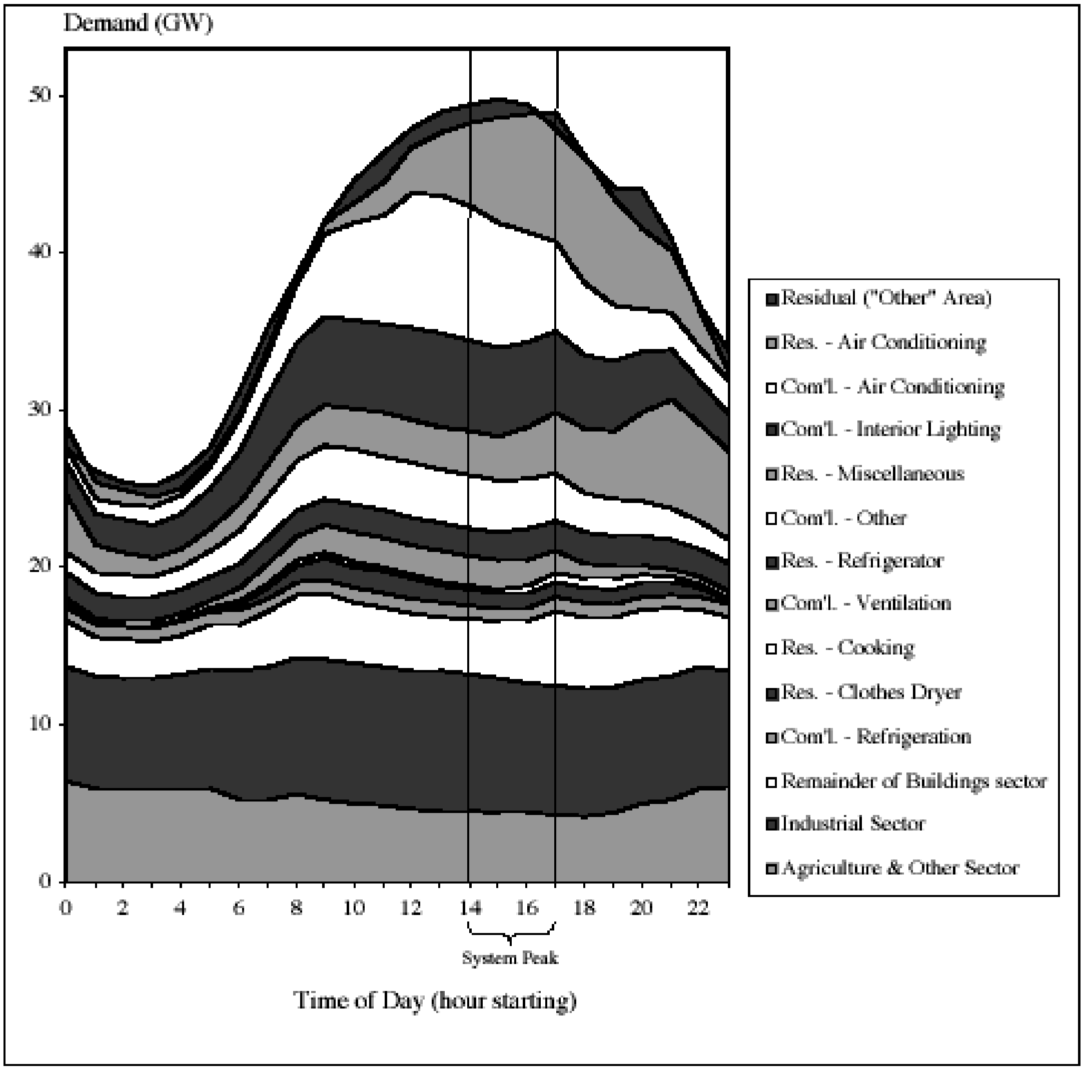
The Carnegie Mellon University
Innovation Works Project

Building as Power Plant

The building as power plant initiative will integrate advanced energy efficient building technologies with innovative distributed energy generation systems, such that most or all of the buildings energy needs for heating, cooling, ventilation and lighting are met on-site, maximizing the use of renewable energies. The combination of energy efficient "ascending" conditioning strategies with "cascading" power-cooling-heating strategies creates the potential for new building projects to become energy exporters – a building as power plant for university, hospital and corporate campuses with growing power demands.

figure 7 (Koomey and Brown 2002)

Figure 1: California 1999 Summer Peak-day End-use Load (GW): 10 largest coincident building-sector end-uses and non-building sectors



Notes: The ten largest coincident building-sector end uses are shown separately, while the smaller building end uses are aggregated together in "Remainder of Buildings Sector." The end uses are ordered the same vertically in the graph and the legend. Res. = residential buildings, Com'l. = commercial buildings. The non-building sectors are shown as sectoral totals. Thus, the buildings sector accounts for all but the bottom two segments of the graph. The Residual (top-most segment) is the difference between FERC system loads and the CEC forecasting model outputs. This difference is mainly due to small utilities not included in the CEC forecasting model. The "Agriculture & Other" sector includes water pumping, transportation and street lighting.

Source: LBNL analysis of CEC and FERC data (Brown and Koomey 2002).